• Soit $f(x,y)$, avec : $x=0,1,2,\ldots,M-1$, et : $y=0,1,2,\ldots,N-1$, une image digitale de taille MxN.

La TFD de $f(x,y)$, $\hat{f}(u,v)$, s'écrit :

$$\hat{f}(u,v) = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\ \exp\{-\imath 2\pi(ux/M + vy/N)\}$$

Remarque : dans le monde continu, on a :

$$\hat{f}(u,v) = \int\int f(x,y)\ \exp\{-\imath 2\pi(ux+vy)\}\ dx\ dy$$

• x et y sont les coordonnées spatiales des pixels de l'image $f(x,y)$

• u et v sont les coordonnées fréquentielles des frequels (frequels = « frequency elements » = les pixels dans le plan de Fourier) de $\hat{f}(u,v)$.

• La TFD inverse s'écrit :

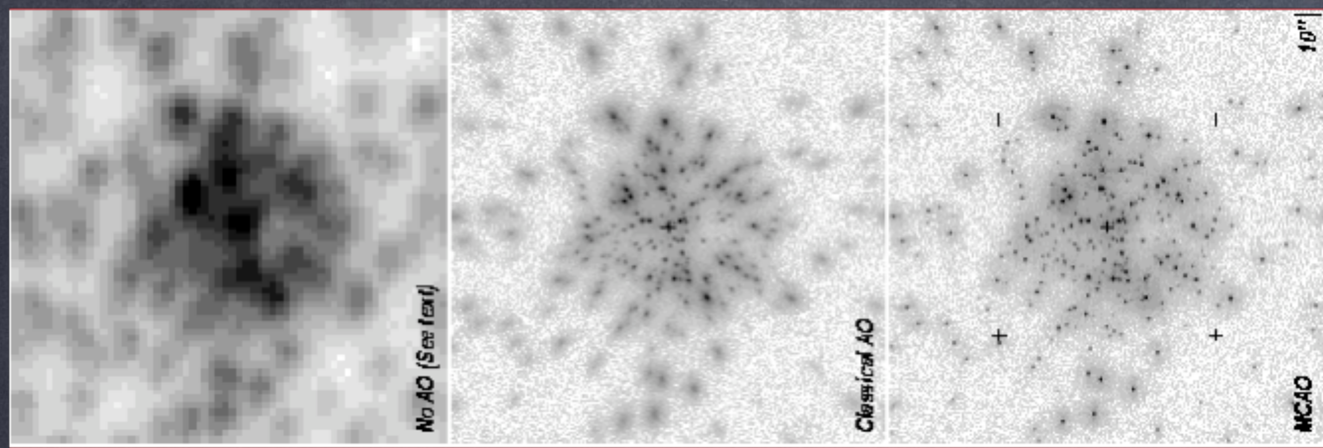
$$f(x,y) = \frac{1}{MN}\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} \hat{f}(u,v)\ \exp\{\imath 2\pi(ux/M + vy/N)\}$$

Même remarque :

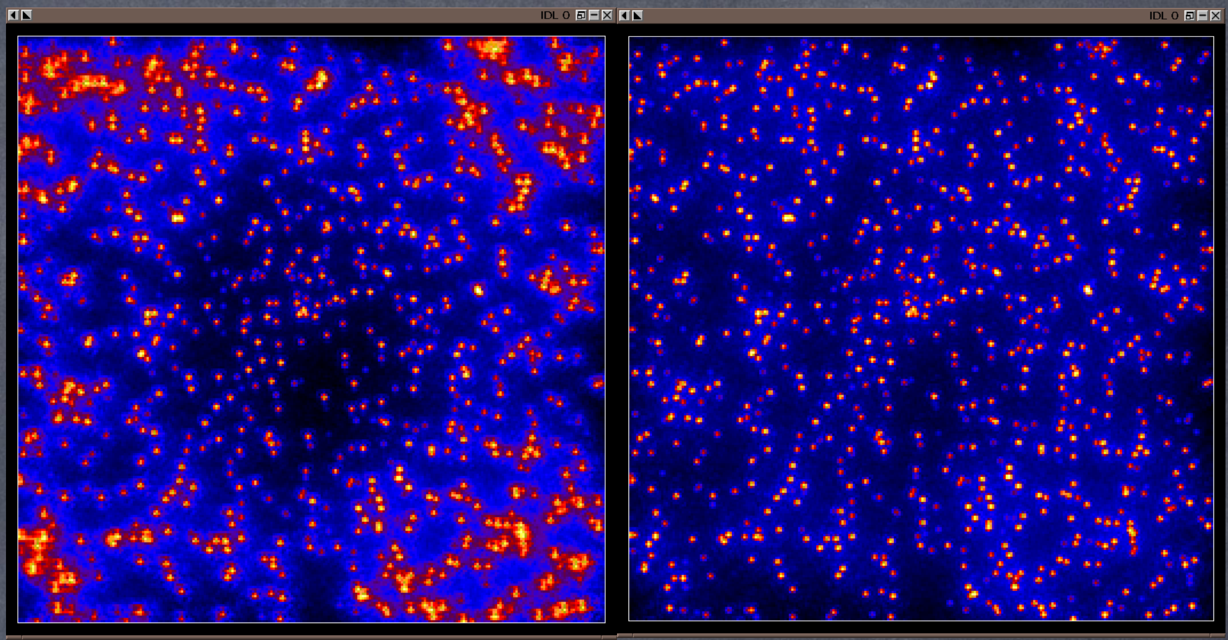
$$f(x,y) = \int\int \hat{f}(u,v)\ \exp\{\imath 2\pi(ux+vy)\}\ du\ dv$$

Anisoplanatic error — 1

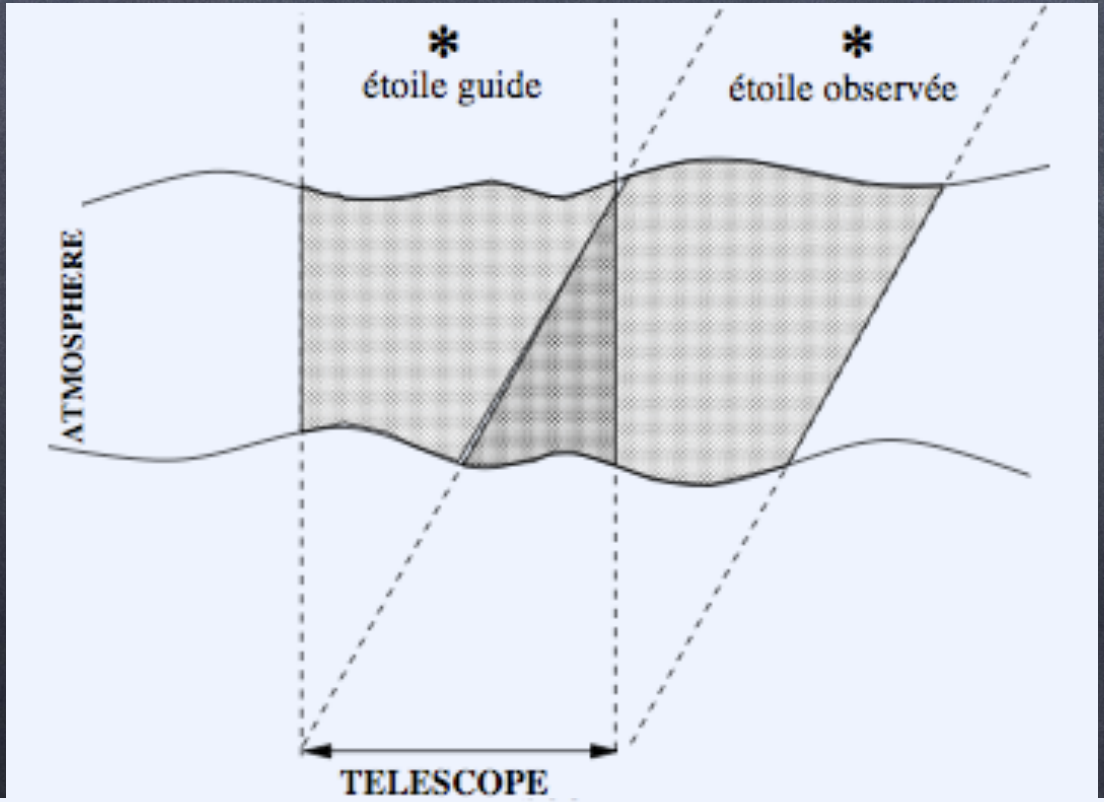
165”



No AO | classical AO (1 DM, 1 NGS) | MCAO (2 DM, 5 NGS)



(bande J, champ de 1’, simu. B.Ellerbroek, Gemini Obs.)

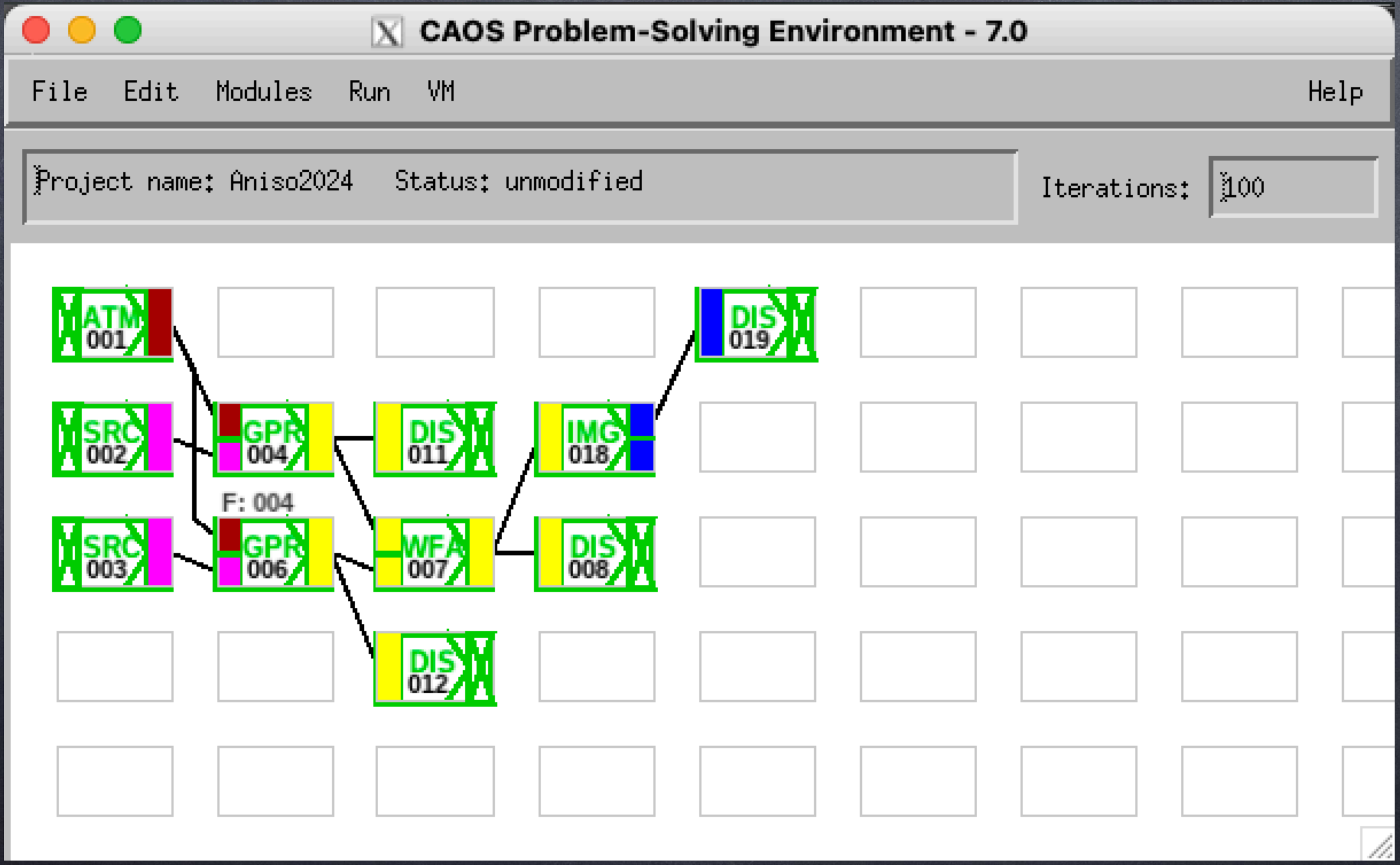


$$\sigma^2_{\text{aniso}} \propto \left(\frac{\theta}{\theta_0}\right)^{\frac{5}{3}}$$

Anisoplanatic error — 2

Numerical tool used for this study: CAOS

(CAOS Problem-Solving Environment + Software Package CAOS + project ``Aniso2024"…)

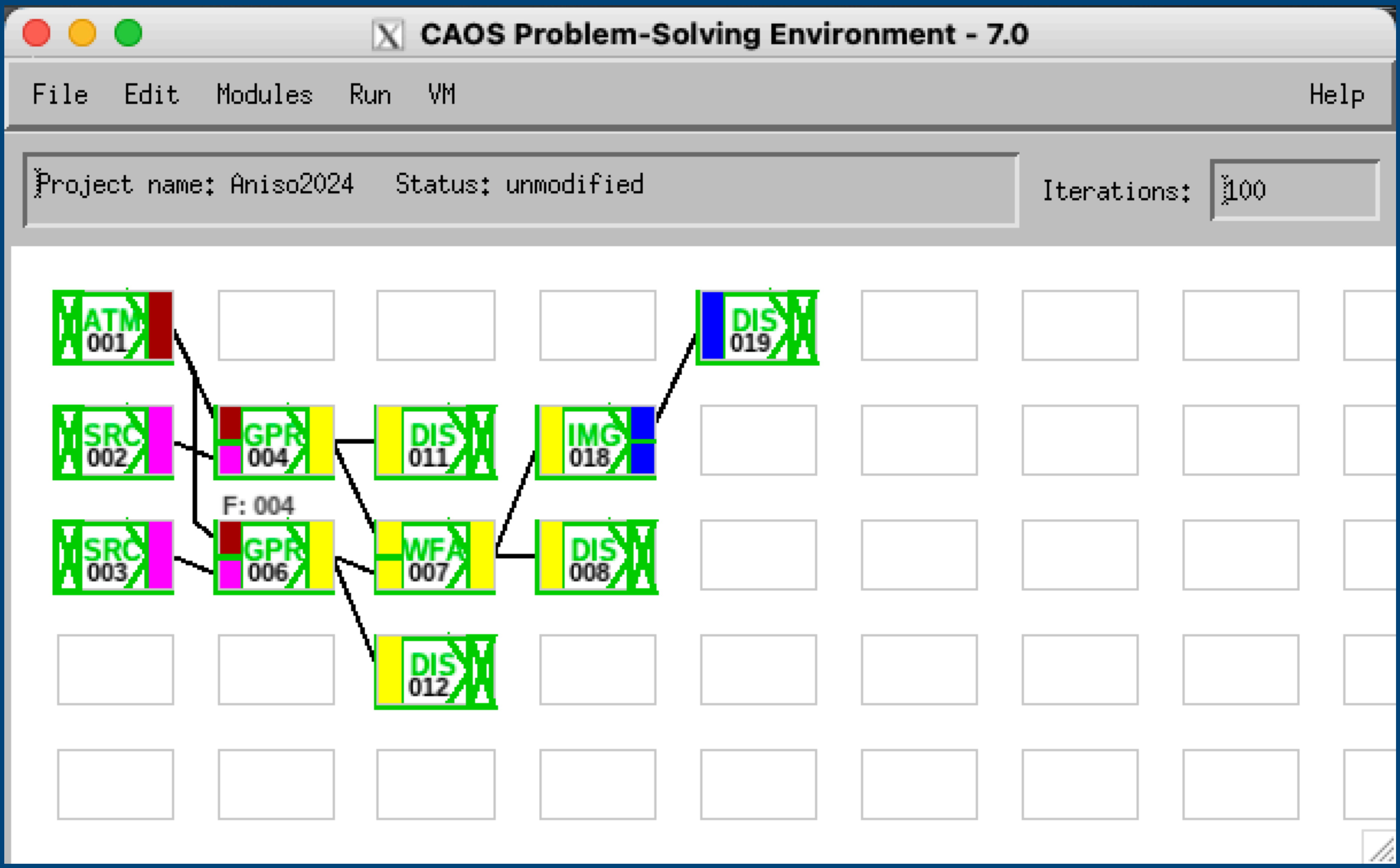


Imaging through the turbulent atmosphere: anisoplanatism ! — 1

Table 1. The 31 modules of the **Software Package CAOS**, version 7.0.

Module	Purpose
[illegible]	
ATM - ATMosphere building	-builds the turbulent atmosphere (FFT+subharmonics, Zernike) (see also utility PSG - Phase Screen Generation)
SRC - SouRCe definition	-characterizes the guide star/observed object
GPR - Geometrical PRopagator	-propagates light from source to telescope through atmosphere
IMG - IMaGing device	-forms an image of the observed object (+detector noises)
Wavefront sensing	
PYR - PYRamid wavefront sensor	-simulates the pyramid wavefront sensor
SLO - SLOpe computation	-computes the slopes from the pyramid signals
SWS - Shack-Hartman Wavefront Sensor	-simulates the Shack-Hartmann (SH) wavefront sensor
BQC - Barycentre/Quad-cell Centroiding	-compute the signals from the SH spots centroiding calculus
IWS - Ideal Wavefront Sensing	-applies "ideal" wavefront sensing (see text)
TCE - Tip-tilt CEntroiding	-computes and reconstructs tip-tilt
Wavefront reconstruction, control & correction	
REC - wavefront REConstruction	-reconstructs the wavefront
TFL - Time-FiLtering	-applies time-filtering after wavefront reconstruction
SSC - State-Space Control	-applies state-space control
DMI - Deformable MIrror	-simulates the behavior of a deformable mirror (DM)
TTM - Tip-Tilt Mirror	-simulates the behavior of a tip-tilt mirror
Calibration	
CFB - Calibration FiBer characterization	-defines a fiber to be used for calibration purpose
MDS - Mirror Deformation Sequencer	-generates a sequence of DM modes or influence functions
SCD - Save Calibration Data	-saves the calibration data (interaction matrix+set of deformates)
Wide-field AO	
AVE - signals AVEraging	-averages measurements from various wavefront sensors
COM - COMbine measurements	-combines measurements from various wavefront sensors
DMC - Deformable Mirror Conjugated	-corrects at different conjugated altitudes
Other modelling modules	
LAS - LASer characterization	-defines laser projector characteristics
NLS - Na-Layer Spot definition	-characterizes the Sodium-layer behavior
IBC - Interferometric Beam Combiner	-combines the light from two apertures
COR - COROnagraphic module	-simulates various coronagraphs (Lyot, Roddier&Roddier, FQPM)
AIC - Achromatic Interfero-Coronagraph	-simulates the Achromatic Interfero-Coronagraph
BSP - Beam SPlitter	-splits the light beam
Other utility modules	
WFA - WaveFront Adding	-adds or combines together wavefronts
[illegible]	[illegible]
IMA - IMage Adding	-adds or combines together images
STF - STructure Function	-calculates the structure function and compares to theory

Imaging through the turbulent atmosphere: anisoplanatism ! – 2



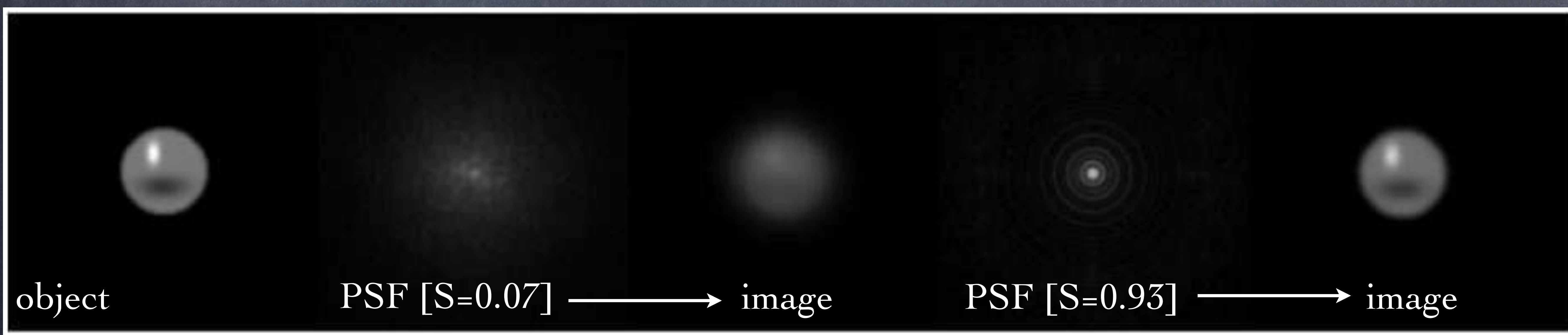
(Another useful metrics: the Strehl ratio)

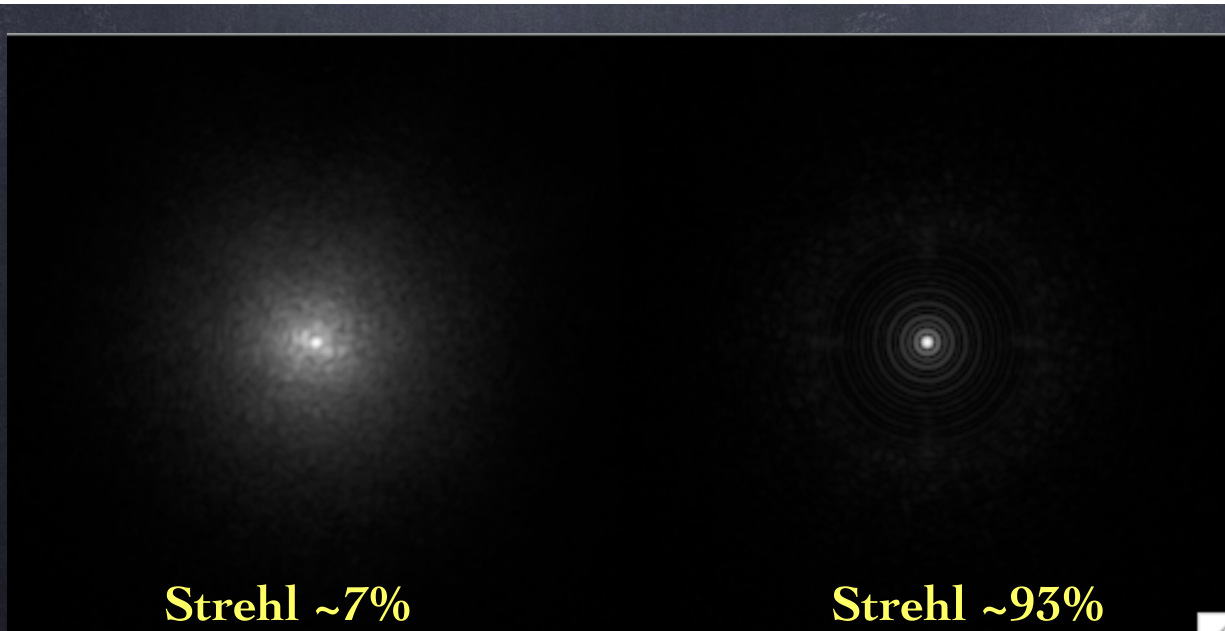
$$S = \frac{I_{\text{post AO}}[0,0]}{I_{\text{perfect}}[0,0]}$$

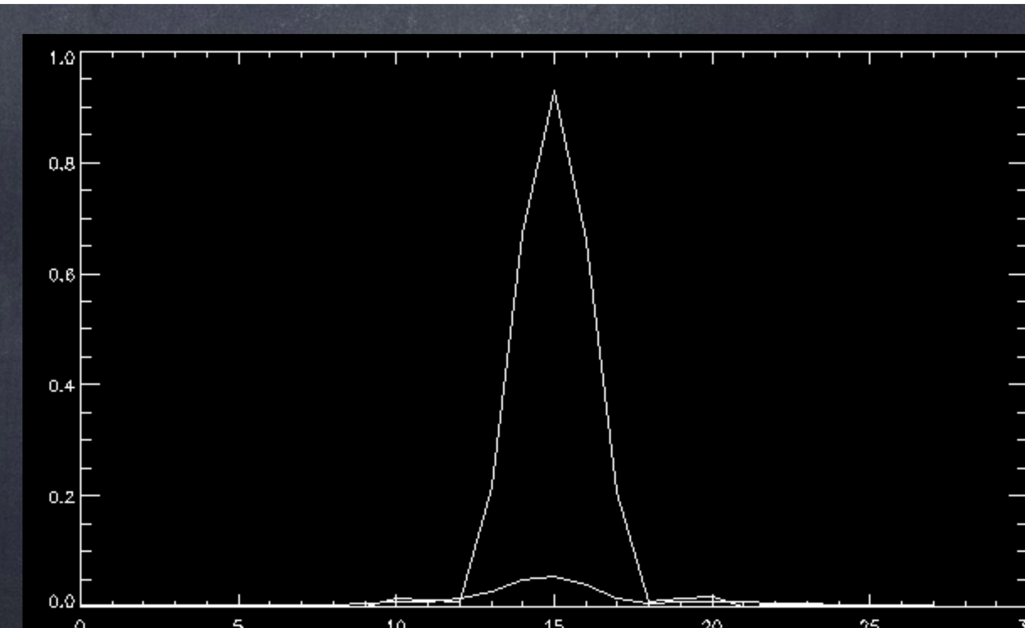
where *I[0,0]* is the intensity of the PSF at the optical center of the field (K. Strehl, Zeit. Instrumenkde 22, 213 (1902)).

$$S \simeq \exp\{-\sigma^2_{\text{post AO}}\}$$

in the framework of the Maréchal's approximation, where the variance (in radians^2) is supposed to be small enough...







(Another useful metrics: the Strehl ratio)

- Approximation that neglects tip-tilt: ratio of the maxima ($S \approx max(I)/max(I_{ideal})$)

- Ratio of the values at the centre of the image ≈ ratio of the OTF (see for example the paper of Roberts et al.)

- From Tokovinin (PASP, 2002):

$$S = \frac{I_{max}}{I_{tot}} \frac{4}{\pi} \left(\frac{\lambda_{CCD}}{D \Delta x} \right)^2$$